Advanced Oxide TFT Technology for OLED Display by Applying ALD Process

Seung-Chan Choi, Kyung-Chul Ok, Jung-Seok Seo, Jae-Man Jang, Jae-Yoon Park, Jun-Ho Lee, Ji-Yong Noh, Tae-Hyoung Moon, Kwon-Shik Park, Soo-Young Yoon
LG Display Co., Ltd., Paju-si, Gyeongki-do, Korea

Abstract

Oxide thin film transistors (TFTs) have been successfully developed by using atomic layer deposition (ALD) process in terms of gate insulator (GI) and oxide channel layer. Oxide TFTs fabricated by ALD process have the several advantages in device reliability and chemical composition controllability over a wide range of mobilities. In this paper, the high mobility (~40cm^2/Vs) and high reliability of oxide TFTs fabricated by ALD process are discussed, and a high resolution (441ppi), high operation frequency (120Hz), 6.58-inch AMOLED panel with an LTPO structure is demonstrated.

Author Keywords

Oxide semiconductor; Thin film transistors (TFTs); ALD; Interface gate insulator; Reliability; High mobility; LTPO

1. Introduction

Oxide TFTs have been widely used in the field of LCD and OLED display.[1,2] The structure with oxide TFTs on top of LTPS (LTPO) has been under mass production in AMOLED display.[3] Conventional LTPO structure in AMOLED display employs one or two switching oxide TFTs in pixel compensation circuit to reduce TFT's leakage current during low refresh rate operation.[3,4] It has been studied to adopt oxide TFTs in both driving and switching TFTs in order to improve panel properties in AMOLED display.[5,6] TFT properties such as better uniformity, more improved reliability and higher mobility are required to apply oxide TFTs to driving TFT in AMOLED display with high resolution and high operation frequency. The various process methods have been attempted to improve the characteristics of TFTs.[7-14]

Recently, atomic layer deposition (ALD) has been widely studied to achieve better device performances in the field of oxide TFTs and display.[8-14] It was reported that thin films fabricated by ALD process exhibit good properties such as high film density and low defects, compared to those by conventional sputter and PECVD process.[8,10] In addition, nano-laminated oxide channel layers employing ALD process were attempted to improve device characteristics because ALD process can effectively control thin film thickness and adjust atomic compositions without breaking vacuum.[13,14].

In this paper, the high mobility (~40cm^2/Vs) and high reliability of oxide TFTs are discussed, focusing on ALD process including interface GI and oxide channel (ACT). Moreover, a high resolution, high operation frequency, 6.58-inch AMOLED panel with an LTPO structure is demonstrated.

2. Experiments and TFT Structure

Fig. 1(a) shows the overall LTPO structure. Top-gate Oxide TFT is formed after completing LTPS process. LTPS and Oxide TFTs share the same source and drain electrodes (S/D) to simplify total TFT's process. We investigated oxide TFT's characteristics with two structures. The first structure has ALD-based interface gate insulator (ALD GI) on sputter-based oxide channel layer and the second structure has ALD-based oxide channel and interface GI are simultaneously applied.

Fig.1(b) shows structure of ALD interface GI. Oxide channel layer (IGZO, 1:1:1) with mobility ~10cm^2/Vs is deposited using a conventional sputter process and then patterned. A thin ALD interface GI (SiO_2) with a thickness of several nm is deposited above oxide channel layer. After completing the ALD interface GI, a thick bulk GI (SiO_2) with a thickness of more than a hundred nm is deposited using a conventional PECVD process.

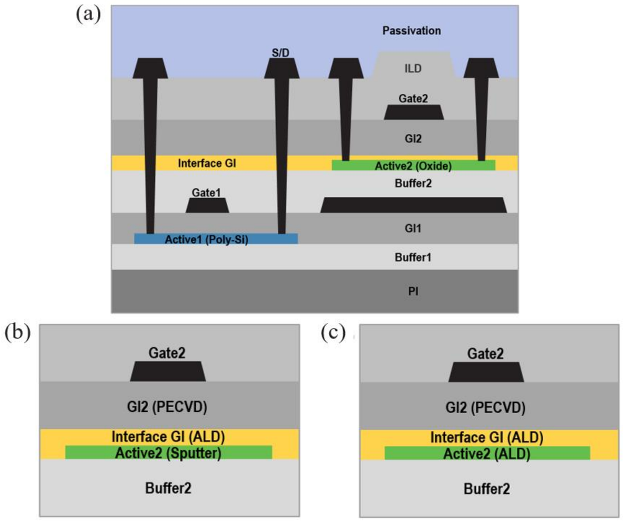


FIGURE 1. (a) Overall structure of LTPO (b) ALD-based interface GI structure on sputtered oxide active. (c) ALD-based oxide active and interface GI structure. () in (b) and (c) indicates process method.

Fig.1(c) shows the structure of ALD oxide channel layer, including ALD interface GI (ALD GI and oxide channel). Compared to the previous structure explained in Fig. 1(b), the difference is that an ALD oxide channel layer with a thickness of tens of nm is applied to replace the sputter-based oxide channel. The entire processes regarding oxide channel, interface GI, bulk GI and others were optimized in order to obtain good TFT properties.

3. Development of ALD based Oxide TFTs

3-1. Evaluation of ALD-based Gate insulator

Fig. 2 shows the structure of a typical coplanar oxide TFT and the defects of the the GI / ACT interface such as excess oxygen

(O_{ex}) and weak Si-O bond. These interface defects (D_{it}) have a great deal of correlation with device reliability. In general, SiO_2 film using PECVD easily forms a high weak Si-O bond and O_{ex} induced e$^-$ trap sites, which can cause the V_{th} positive shift.[15] To minimize the e$^-$ trap sites, the process of depositing the high-quality SiO_2 thin film using ALD and then depositing PECVD SiO_2 was applied as a double GI concept. In addition, this process has the advantage of reducing the total process time due to the low deposition rate of ALD process.

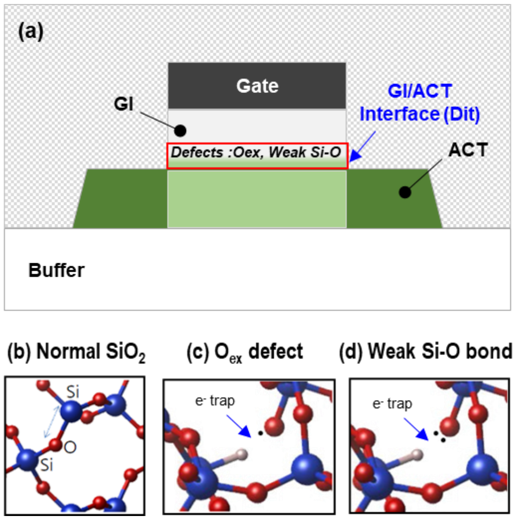


FIGURE 2. (a) Typical coplanar oxide TFT structure and various formation of SiO_2 bonds such as (b) Normal SiO_2, (c) O_{ex} defects and (d) Weak Si-O bond.

Fig. 3 represents the result of the chemical composition of PECVD and ALD SiO_2 films in terms of (a) relative oxygen contents and (b) relative hydrogen contents. While the similar composition of oxygen is observed, the composition of hydrogen was decreased by ~43%. The deposition conditions of ALD SiO_2 were optimized to reduce hydrogen contents, which affect degradation of V_{th} uniformity.

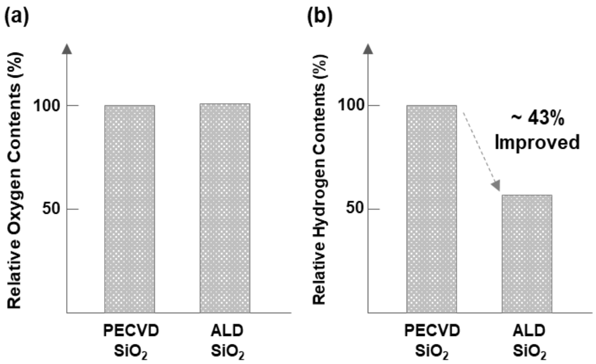


FIGURE 3. Comparison of chemical compositions of PECVD and ALD SiO_2 in terms of (a) Relative Oxygen contents and (b) Relative Hydrogen contents.

Fig. (4) shows the breakdown voltage (BV) of PECVD and ALD SiO_2. The BV characteristics were improved from ~3mV/cm (PECVD SiO_2) to 10mV/cm (ALD SiO_2). It can be interpreted using the bulk-limited conduction mechanism (Poole-Frenkel emission model) from the current flowing through the dielectric. The superior properties of BV could be attributed to the higher film density of ALD SiO_2 (ρ ~2.32 g/cm^3) compared to PECVD SiO_2 (ρ ~2.28 g/cm^3). Breakdown phenomena are typically induced by defects such as weak Si-O bonds within the dielectric. Therefore, it can be inferred that the stable Si-O bonds in ALD SiO_2 leads to an improvement of BV characteristics.

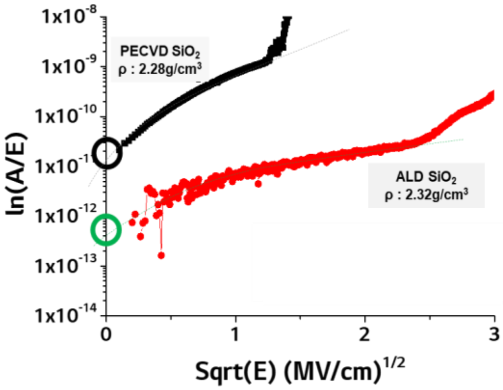
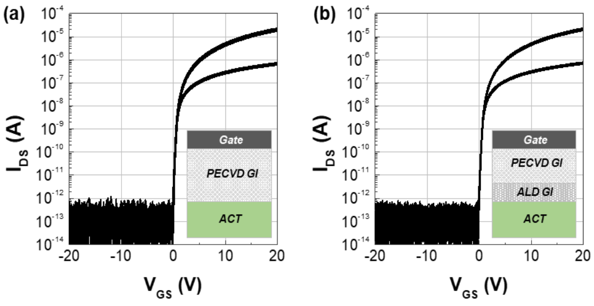


FIGURE 4. Breakdown voltage of PECVD and ALD SiO_2 plotted by ln(A/E) and sqrt (E). ρ indicates the density of SiO_2 thin film.

Fig. 5 shows initial transfer characteristics of TFT devices fabricated by (a) PECVD GI and (b) PECVD + ALD GI, respectively (as shown in Fig 1(b)). The similar device characteristics such as V_{th} and mobility were observed in both devices. Even if ALD SiO_2 is applied to the interface, the initial device characteristic shows good uniformity.



	(a) PECVD GI	(b) PECVD + ALD GI
V_{th} (V)	1.12	1.16
Mobility (cm^2/Vs)	10.20	10.23

FIGURE 5. Initial transfer characteristics of TFT devices fabricated by (a) PECVD GI and (b) PECVD + ALD GI, respectively.

Fig. 6 represents time dependence of PBTS under V_{GS} = 30V and 60°C for 3hrs in TFT devices fabricated by PECVD and PECVD + ALD GI. Compared with TFT devices of PECVD GI, the device reliability of PBTS was improved by ~ 24% in PECVD + ALD GI. While the reliability characteristics are comparable up to 2000sec, it is evident that the degradation is reduced after 2000sec in PECVD + ALD GI. It is implied that the acceleration of long-term reliability was efficiently suppressed by reducing the deep level defects such as O_{ex} and weak Si-O bond.

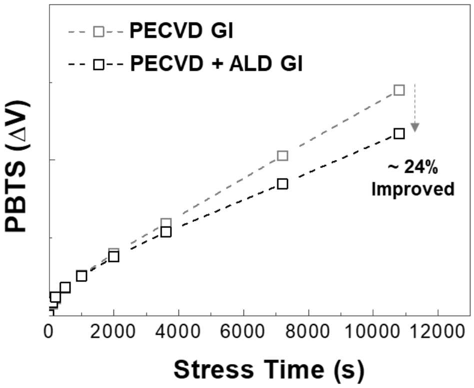


FIGURE 6. Time dependence of PBTS under V_{GS} = 30V and 60oC for 3hrs in TFT device fabricated by PECVD and PECVD + ALD GI.

3-2. Evaluation of ALD GI and oxide channel

The chemical composition of the oxide channel as the active (ACT) layer is a key factor in determining mobility. This mobility is mainly controlled by In, Ga, and Zn, which have percolation conduction path of the s-orbital, and ALD has the advantage of precisely adjusting these chemical compositions by controlling the amounts of three different In, Ga, and Zn source precursors. Especially since driving TFTs require high driving current in the panel, it is necessary to implement devices that have high mobility and reliability. The evaluation of oxide TFTs fabricated by ALD GI and oxide channel was conducted to achieve high mobility and reliable device with the structure as shown in Fig. 1(c).

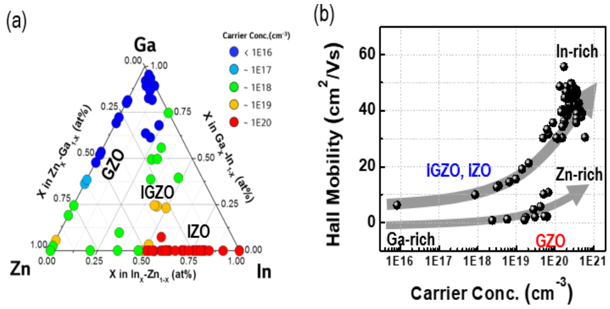


Figure 7. (a) Chemical composition (In/Ga/Zn) and carrier concentration (b) Hall mobility characteristics according to carrier concentration for IGZO, IZO, and GZO.

Fig. 7(a) shows various chemical composition (In/Ga/Zn) and carrier concentration of oxide thin films deposited using the ALD method. Indium based thin films such as IZO, IGZO exhibit relatively higher carrier concentrations, compared to GZO thin film. In general, it is known that Indium and Gallium act as carrier generator and suppressor, respectively. Although the carrier concentration is the same, thin films with a higher indium content have higher hall mobility, as shown in Fig. 7(b). This behavior is known to be related to the electrical conduction mechanism caused by the 5s orbital overlap of indium.

Fig. 8 shows the initial transfer characteristics of oxide TFTs according to Indium composition. Each device applied the same GI2/Buffer2 deposition conditions (as shown in Fig. 1(c)). As the indium content increases, the mobility of the TFT devices increases in a similar trend to the previous thin film results. This ALD process of oxide channel has advantage for wide range of mobilities from low to high by controlling the chemical compositions of In/Ga/Zn.

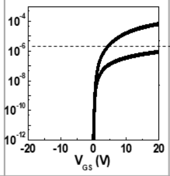
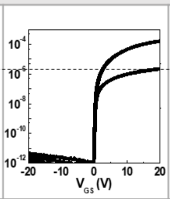
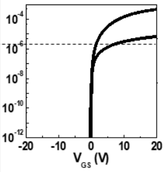
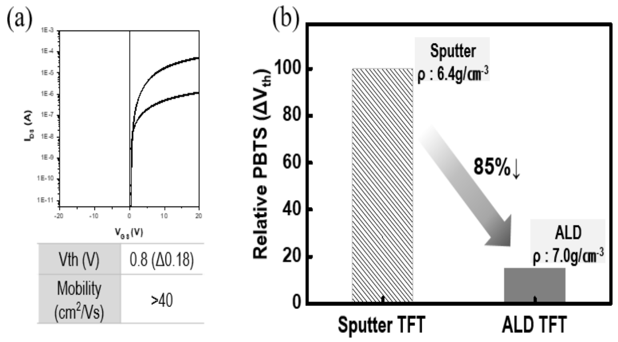
	Electrical Characteristics		
Transfer Characteristics			
In composition (at.%)	35	45	84
Mobility (cm^2/Vs)	7.8	19.7	50.4
V_{th} (V)	1.5	0.5	0.1
S.S (V/Dec.)	0.15	0.12	0.09

FIGURE 8. Initial transfer characteristics of oxide TFTs with ALD GI and oxide channel, according to Indium contents.

Fig. 9(a) shows the transfer characteristics of a high mobility oxide TFTs fabricated by ALD process (GI and oxide channel). The TFT fabrication processes including ALD process as well as PECVD GI2 and Buffer2 were optimized in terms of initial V_{th} and reliability. This optimization processes were implemented to supply a sufficient amount of oxygen to remove oxygen vacancies in the oxide channel and to provide an adequate amount of hydrogen to passivate defects without degrading the initial V_{th}.

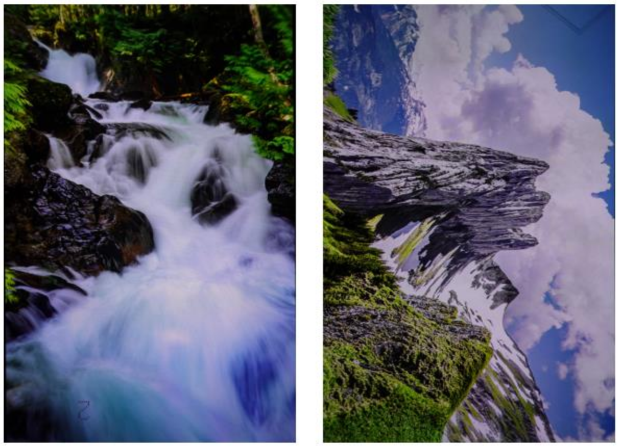


Vth (V)	0.8 (Δ0.18)
Mobility (cm^2/Vs)	>40

Figure 9. (a) Initial transfer characteristics, (b) Relative threshold voltage shift under PBTS and the density (ρ) of oxide thin film.

Fig. 9(b) represents reliability characteristics of improved oxide TFTs including ALD GI and oxide channel under PBTS (V_{GS}=30V, 60°C for 11hr). The reliability is drastically improved by ~85%, in optimized ALD oxide TFTs compared to sputter TFTs. The oxide channel deposited by ALD process exhibits a higher film density, compared to conventional sputter film as shown in Fig. 9(b). This implies that ALD process can be effective to deposit high quality and dense thin film, which have a lower defect.

Fig. 10 shows display image of AMOLED panel with LTPO structure and high resolution. Two ALD layers (interface GI and oxide channel) were applied to this panel. Panel operated stably from 1Hz to 120Hz and represented good panel performances in terms of luminance uniformity and color characteristics.



Item	Specification
Panel Size	6.58inch (71.1 x 164.89)
A/A size	69.12 x 152.06mm
Resolution	1200 x 2640 (441ppi)
Refresh rate	1~120Hz

FIGURE 10. Display image and specifications of 6.58-inch AMOLED panel with LTPO structure. Both ALD-based interface GI and oxide channel are simultaneously applied.

4. Conclusion

We successfully developed oxide TFTs, and AMOLED panel based on ALD process. The deposition conditions of PECVD + ALD GI (interface) were optimized to obtain uniformity and reliability of device due to their low hydrogen contents and high film density. The oxide channel layer deposited by ALD process has advantage for wide range of mobilities from low to high by controlling the chemical compositions of In/Ga/Zn. The optimized oxide TFTs fabricated by ALD process (interface GI and oxide channel) show high mobility and reliability.

Finally, we demonstrated the feasibility of ALD process with high-resolution AMOLED panel of LTPO structure which simultaneously applied ALD process (interface GI and oxide channel). This panel revealed good performances. ALD process can be one of candidates for AMOLED display.

5. References

1. N. Y. Gong, et al. "Implementation of 240Hz 55-inch Ultra Definition LCD Driven by a-IGZO Semiconductor TFT with Copper Signal Lines" SID 2012 DIGEST, 58.2, pp. 784-787
2. C. I. Park, et al. "World's first large size 77 inch transparent flexible OLED display" J. SID 26/5, pp. 287-295 (2018)
3. T. K. Chang, et al. "LTPO TFT Technology for AMOLEDs" SID 2019 DIGEST, 39-3, pp. 45-548
4. U. J. Chung, et al. "Manufacturing Technology of LTPO TFT" SID 2020 DIGEST, 15.1, pp. 192-195
5. J. S. Park, et al. "High Mobility Oxide Thin-film Transistors for AMOLED Displays" SID 2022 DIGEST, 4-3, pp. 20-23
6. G. Yan, et al. "Development of High Mobility and Reliability Metal Oxide TFT for 13.2 inch AMOLED Display" SID 2024 DIGEST, 14-2, pp. 154-157
7. N. Kimizuka, et al. "Physics and Technology of Crystalline Oxide Semiconductor CAAC-IGZO : Fundamentals, John Wiley & Sons (2016)
8. J. Sheng, et al. "Amorphous IGZO TFT with High Mobility of ~70 cm2 /(V s) via Vertical Dimension Control Using PEALD" ACS APPLIED MATERIALS & INTERFACES, v. 11, no. 43, pp. 40300-40309 (2019)
9. M. H. Cho, et al. "Comparative Study on Performance of IGZO Transistors With Sputtered and Atomic Layer Deposited Channel Layer" IEEE TRANS. ON ELECTRON DEVICES, VOL. 66, NO. 4, pp. 1783-1788 (2019)
10. S. G. Jeong, et al. "Hydrogen Impacts of PEALD InGaZnO TFTs Using SiOx Gate Insulators Deposited by PECVD and PEALD" IEEE TRANS. ON ELECTRON DEVICES, VOL. 67, NO. 10, OCTOBER, pp. 1250-1255 (2020)
11. Y. S. Kim, et al. "Reliability Engineering of High-Mobility IGZO Transistors via Gate Insulator Heterostructures Grown by Atomic Layer Deposition" Adv. Mater. Interfaces 2024, 11, 2301097
12. H. J. Lee, et al. "Enhanced IGZO TFT Performance with Atomic Layer Deposition Parameter Optimization for Large OLED Displays" SID 2024 DIGEST, 97-3, pp. 1250-1253
13. H. M. Kim, et al. "Atomic layer deposition for nanoscale oxide semiconductor thin film transistors: review and outlook" Int. J. Extrem. Manuf. 5, 012006 (2023)
14. H. J. Jeong, et al. "Plasma-enhanced atomic-layer deposition of active layers of nanolaminated (InOx)n (GaZnOy)m for thin-film transistors" J. Mater. Chem. C 20, pp. 7831–8 (2022)
15. S. Oh, et al. "Effect of interfacial excess oxygen on positive-bias temperature instability self-aligned coplanar InGaZnO thin-film transistors" Appl. Phys. Lett. 108, 141604 (2016)